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FACTORS SURROUNDING MOTION PLATFORM - VISUAL SYSTEM COUPLING IN FLIGHT SIMULATORS

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Some of the factors affecting the behavior of motion systems and visual systems used simultaneously are considered. In particular, the flight visual - motion coupling problem is addressed, with respect to the necessary iteration rates of inputs, outputs, and the iteration rates of numberical computations. Data is presented for several OFT/WST having both motion and visual systems. Conclusions and recommendations are drawn, based upon the results obtained.

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SECTION I

INTRODUCTION

The purpose of this investigation was to look into the various problems of coordinating the behavior of a motion system and a visual scene as used with a Weapons System Trainer (WST) or Operational Flight Trainer (OFT) simulator. If the motion and visual cues are not properly synchronized with the pilot inputs, negative training effect results. Thus, phase lag becomes an important item in such an investigation.

Initially, the investigation was to be addressed to the following areas:

a. The overall flight trainer system analysis which would include the flight dynamics, the motion base dynamics and the electro/mechanical coupling with a visual system.

b. How the flight trainer utilizes the capacity of the system to realistically activate the motion base and coupled visual system.

c. To define the excursion envelope of motion base systems.

d. Determine how the aircraft aerodynamic math model is modified to function within the motion platform envelope. This is important because the aerodynamic flight envelope normally exceeds the motion platform envelope, and a scheme to wash out the motion must be used.

Due to the time constraints with which to gather data, reduce and analyze it, and arrive at conclusions, the entire scope could not be investigated to its fullest. With this constraint, it was decided to investigate the fact of whether the digital computer was iterating computations at a sufficient rate, so as to not introduce noticeable phase lag. In a sense, this touches each of the aforementioned regions, but simultaneously reveals there is still much to be done in each of the areas.

Items considered important in arriving at any conclusions were gathered as data from simulators having both motion and visual systems. Although this limited the number of samples, the data collected indicates trends. Various portions of the data are supported by a theoretical model. Topics considered relevant as data were the following:

a. The natural frequency of the motion system

b. The iteration rates of the 6DOF equations of motion used in the computer

c. The sampling rate for the stick input to the computer

d. The output rate from the computer to the motion system

e. The output rate from the computer to the visual system

f. The dynamic parameters of the visual system gantry

g. Properties of the visual system in general.

With respect to the visual system, must have a cathode-ray tube for the visual presentation. Due to the various phosphorus that can coat the tube, and the associated persistence of the particular phosphor, the rate of update to the screen can vary, and a flicker problem can or cannot be evident. Phosphors with the ability to retain the illumination for long periods of time would require a slower update rate. Because of this variable, the various visual presentation methods and update rates to the phosphor screen bring a new variable into the study. Therefore, the update rate to the visual system is mentioned without consideration to the persistence aspect.

Of the trainers for which information was gathered, one had a model board TV system, one had a Variable Amorphic Motion Picture (VAMP) system and two had a computer generated visual scene.

The hydraulic motion system providing the acceleration cues to the pilot is assumed to operate in a smooth manner, as well as having the computer outputs smoothed by some algorithm scheme. Providing smoothness in the motion system is a problem external to the scope of this investigation.

SECTION II

MODEL AND THEORETICAL CONSIDERATIONS

A model of the sampled-data, hydraulically driven motion base system was established, and an analysis performed on the model. It was desired to determine if any correlation existed in data obtained from simulators in the field and the theoretical analysis.

To establish the minimum sampling rate required, a model is set forth. The model is assumed to have a zero order hold, representing the sample rate and digital computer, followed by a second order system indicative of the hydraulic motion system. The motion system generates both position and velocity feedback signals. The error signals are then formed from the computations based on pilot input and feedback signals from the motion system. A block diagram for a system of this nature is shown in figure 1.

The Laplace transform representation of the open loop transfer function of figure 1.

$$\frac{B}{E}(s) = \left[\frac{1-e^{-ts}}{s}\right] \left[\frac{K_p(K_v S + 1)}{\frac{s^2}{w_n^2} + \frac{2\zeta}{w_n} s + 1}\right]$$

The solution of this equation for step inputs at e, in the time domain is

$$y(T) = K_p K_v \left[\delta(T) - 1 + e^{-\zeta \omega_n T} \sec \theta \cos\left(\omega_n \sqrt{1-\zeta^2}\, T + \theta\right)\right]$$

where $\theta = \tan^{-1}\left(-\frac{\zeta}{\sqrt{1-\zeta^2}}\right)$, and T is the length of time between successive samples.

The phase shift will be a result of the cosine term. The Link 6DOF, 48-inch stroke motion system has a performance of 45 degrees phase lag at 2Hz, and a natural frequency of about 5Hz. The damping is estimated to be somewhat less than optimum (0.7). Using this information as baseline data, the sampling time, T, can be computed.

Using a damping factor of $\zeta = 0.5$ the interaction rate should be 20.8 iterations per second to allow 45 degrees phase lag. For $\zeta = 0.6$ the iteration rate should be 17.8 iterations per second. These values agree closely with the iteration rates being used on trainers in the field of 15 or 20 times per second.

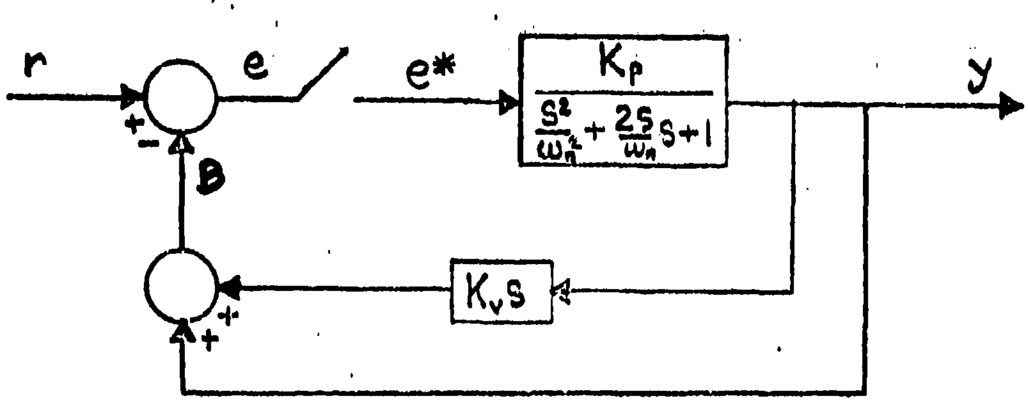

Figure 1. Sampled Data Hydraulic Motion System Model.

SECTION III

TRAINERS AND DATA

The trainers for which data is listed are the following: Device 2F86, a simulator for the F4E Phantom II aircraft; Device 2F90, a simulator for the TA4J Skyhawk aircraft; Device 2F103, a simulator for the A7E Corsair II Aircraft Night Carrier Landing Trainer; and Eastern Airline's L-1011 Tristar Aircraft Simulator. The first three aircraft are high performance fighter or attack, military jet aircraft, the latter being a wide body commercial jumbo jet for passenger transportation.

In considering the scope and objectives of the investigation, the following topics were deemed pertinent in collecting supporting data:

a. The rate at which the computer receives new inputs from the pilot's stick

b. The rate at which the computer iterates the computations the six degree-of-freedom equations

c. The rate at which the computer and/or the D/A converter updates the motion base position

d. The output rate from the computer to the visual system

e. The dynamic parameters of the motion base system such as natural frequency, damping factor or time constants

f. The physical capabilities of the motion base such as maximum travel, maximum pitch, roll, yaw, maximum velocity and acceleration in each of the six axes

g. The means by which the visual display is generated and displayed. The presentation of table 1 gives a condensed tabular form of the data collected.

TABLE 1. COMPARISON OF FOUR SIMULATORS

	2F86	2F90	2F103	Eastern L-1011
Rate at which computer receives new inputs from pilot's stick	$20 \frac{\text{iterations}}{\text{sec}}$	$20 \frac{\text{iterations}}{\text{sec}}$	$20 \frac{\text{iterations}}{\text{sec}}$	$20 \frac{\text{iterations}}{\text{sec}}$
Rate at which computer iterates 6DOF aero. equations	aero $10 \frac{\text{iterations}}{\text{sec}}$ misc $20 \frac{\text{iterations}}{\text{sec}}$	$20 \frac{\text{iterations}}{\text{sec}}$	$20 \frac{\text{iterations}}{\text{sec}}$	$20 \frac{\text{iterations}}{\text{sec}}$
Rate at which motion base is updated	aero $10 \frac{\text{iterations}}{\text{sec}}$ misc $20 \frac{\text{iterations}}{\text{sec}}$	$20 \frac{\text{iterations}}{\text{sec}}$	$20 \frac{\text{iterations}}{\text{sec}}$	20 or 10 $\frac{\text{iterations}}{\text{sec}}$
Output rate from computer to visual system	$20 \frac{\text{iterations}}{\text{sec}}$	$20 \frac{\text{iterations}}{\text{sec}}$	$25 \frac{\text{iterations}}{\text{sec}}$	20 or 10 $\frac{\text{iterations}}{\text{sec}}$
Dynamic parameters of the motion base system	w_n of 6-10 Hz	Healy-Cooper data not reduced		
Type of aircraft	F4E	TA4J	A7E	L-1011
Dynamic parameters of visual system gantry	w_n 6 Hz	Computer generated images	Computer generated images	VAMP
Washout equations				
Physical capabilities of motion system	Refer to report text			

SECTION IV

DISCUSSION

The simulator for the A7E aircraft to train pilots for night carrier landing provided much data, both in the motion and visual areas of interest. The visual display is computer generated and cycled at a rate of 25 times per second. The sampling rate of the stick for motion and visual is under the executive program control within the digital computer, and thus this parameter varies in time. Although this variance exists, the NCLT operational program executive is cycled at a minimum of 33 times per second.

The aerodynamic equations used by the digital computer for the A7E aircraft were noted to be reduced from coupled second order differential equations to ordinary first order differential equations.[1]

Two different wash-out equations are used on the A7E NCLT, Device 2F103. The general form of the washout filter is $\frac{\tau s}{\tau s+1}$. This filter rejects the low frequency signals and passes the higher frequency signals. In a plot of amplitude ratio vs frequency this appears as the Bode plot shown in figure 2.

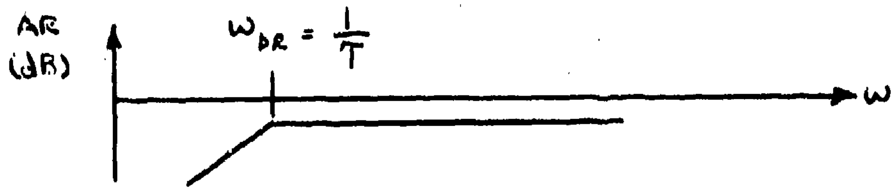

Figure 2. Frequency Characteristics of a Typical Washout Filter

In the roll axis, ϕ, the time constant τ is 2 sec, giving a break frequency of F=0.079 Hz. The Yaw, ψ, and pitch, θ, motion both have the same time constant associated with them: τ = 1.5 seconds. This results in a break frequency of 0.106 Hz.

The physical capabilities of the motion system for the 2F103 are as follows:

[1]Technical Manual - NAVTRADEV P-3690

		position	velocity	acceleration
pitch, θ	$\pm$	10 degrees	16 deg/sec	150 deg/sec^2
roll, ϕ	$\pm$	20 degrees	32 deg/sec	360 deg/sec
Yaw,	$\pm$	10 degrees	18 deg/sec	150 deg/sec

This particular motion system is supported at the rear of the cockpit and is considered to be a three degree-of-freedom motion base.

Device 2F90 is the simulator for the TA4J Skyhawk Aircraft. This training device has a hydraulically driven motion base and a computer generated visual display that is projected on a screen in front of the cockpit. A Nova 800 computer interfaces the visual system and the motion base.[2]

The stick inputs from the pilot-trainee are sampled at a rate of 20 times per second. This same sample rate is also used on the iteration of the solutions to the aircraft six degree-of-freedom aerodynamic equations and the rate at which the computer outputs updated data to the motion system. The computer outputs data to the visual system at 20 times per second, but the visual iterations are 30 times per second.

Physically, the motion base of Device 2F90 operates at 1000 psi hydraulic pressure, and can pitch $\pm$ 15 degrees, roll $\pm$ 15 degrees, and has a vertical translation of $\pm$ 6 inches.

The following information was obtained from Singer-Link personnel on the F4E No. 18 Simulator. This simulator has a Link 48-inch 6DOF motion base, which has a bandpass of up to 2 or 3 Hz.

The iteration rate for the aerodynamic motion effects and the motion system lag length computations are done at a rate of 10 iterations per second. The Advanced Student Undergraduate Pilot Trainer (ASUPT) has 15 iterations per second and considered somewhat marginal. The miscellaneous motion effects which include runway rumble, speed brakes, gear and flap effects are done at 20 iterations per second.

The sampling rate for the stick input to the computer is 20 iterations per second. It might be noted that some commercial simulators use 10 iterations per second.

Output rate from the computer to the motion system is dependent on the digital to analog converters. All the D/A converters on this particular simulator are outputted at a rate of 20 per second, but since the aerodynamic equations are computed only 10 times per second, their effective output rate is 10 per second.

[2] Healy, L.D. and Cooper, F.R., VERIFICATION OF SIMULATOR PERFORMANCY BY FREQUENCY RESPONSE MEASUREMENT, Naval Training Equipment Center, Orlando,FL

The Singer Mark 5 visual system to be used with this simulator is still under construction. The gantry-camera arrangement is expected to have a response to 6 Hz or greater.

Eastern Airlines has a Singer 60-inch 6 DOF simulator installed at their Miami training facility. This simulator is for the Lockheed wide body L-1011 aircraft.

The rate at which the input is sampled, and at which the computer iterates the 6 DOF aerodynamic equations is 20 times per second.

The rate at which the motion system and visual system receive updated outputs from the computer is dependent on how the data is stored in the D/A converters. Due to this fact, it can be 20 or 10 times per second. The visual system is the VAMP type display.

Several additional simulators are known to exist that have both visual and motion systems, which were not considered. These simulators are for transport size aircraft and not high response fighter or attack type aircraft.

Three of these are commercial simulators and might be of interest for transport size aircraft. These are located at Northwest Airlines in Minneapolis, Minnesota, United Airlines in Denver, Colorado, and American Airlines at Fort Worth, Texas.

Also in the line of larger aircraft is the simulator for the B-1 bomber. This simulator is located at North American Rockwell in Los Angeles, California.

The simulators are currently under construction at the Singer-Link plant in Binghamton, New York. One is the Air-to-Air Combat Simulator built on the Link 60-inch 6 DOF motion system. The other is ASUPT. The latter is for the T-37 aircraft, while the former can be programmed as an F-4, F-15, or other high performance aircraft.

The ASUPT simulator in late summer 1973 was being transferred to Williams AFB, Arizona, having completed the in-plant acceptance testing at Singer-Link in Binghamton, New York.

Data on both of these simulators should be available in the future. Data on the larger, slower responding aircraft might be of interest, but in light of smaller attack-fighter type aircraft, the data on the ASUPT and Air-to-Air Combat Simulator would be more significant.

Based on the theoretical analysis and data collected on simulators in the field, iteration rates of 20 times per second for attack and fighter type aircraft appear to be appropriate. The Singer-Link Air Force ASUP simulator for the T-37 aircraft was informally judged marginal using iteration rates of 15 times per second while 10 times per second seems to be adequate for commercial type aircraft. Considering the maneuvers and performance ability of the various types of aircraft, these figures do not appear to be misaligned. The motion base update rate of 20 times per second appears to be baseline for fighter type aircraft. The visual presentation data tends to support an update rate of 30 times per second.

SECTION VI

RECOMMENDATIONS

It was discovered during the execution of the work contained herein that basic areas were in need of further investigation and could possibly serve as topics for further study.

In collecting the data pertinent herein it became apparent that the information flow path from the pilot input, through the computer, to the motion system is not clearly defined. Such a definition in this particular area could conceivably result in a better training device by aiding the manufacturer, and resulting in a more acceptable motion system.

Through discussions with various personnel in gathering information for the visual system behavior, the signal path again appears to be non-defined and in some cases even misaligned in the expedient flow of signals resulting in unwanted phase lag. Further investigations in this particular area appears to be a worthwhile effort.

The means in which the digital computer arrives at commands to the visual and/or motion system is somewhat unclear too. Whether the use of second order, coupled, differential equations, or simplified first order differential equations is sufficient appears to be a topic worthy of further study.

As a final recommendation, possible further work in the area of washout filters and washout schemes could be considered. This area is one in which understanding and reason seem to be almost emperical.

In any of these four areas, further study and investigation might prove advantageous in the procurement and utilization of OFT/WST used to train pilots. As a result better trained personnel would be ready for duty.